



METHOD OF TRANSMITTING PILOT TONES IN A MULTI-SECTOR CELL,  
INCLUDING NULL PILOT TONES, FOR GENERATING CHANNEL QUALITY  
INDICATORS

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IN MULTI-SECTOR CELLS

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RELATED APPLICATIONS:

The present application claims the benefit of U.S. Provisional Patent Application  
S.N. 60,449,729 filed February 24, 2003.

FIELD OF THE INVENTION:

The present invention is directed to wireless communications systems and, more  
particularly, to methods and apparatus for transmitting pilot signals in a multi-sector cell,  
e.g., a cell with synchronized sector transmissions.

BACKGROUND OF THE INVENTION:

In a wireless communications system, e.g. a cellular system, the channel  
conditions are an important consideration in the operation of the wireless system.  
Within a wireless communications system, a base station (BS) communicates with a  
plurality of wireless terminals (WTs), e.g., mobile nodes. As a wireless terminal moves  
to different locations within the base station's cell, the condition of the wireless  
communication channel between the base station and the wireless terminal may  
change, e.g., due to varying levels of noise and interference. The noise and  
interference experienced by the wireless terminal's receiver may include background  
noise, self-noise, and inter-sector interference. The background noise may be  
classified as independent from the base station's transmission power level. However,  
the self-noise and inter-sector interference are dependent on the base station's  
transmission power level, e.g. the transmission power in one or more sectors.

One method typically used to evaluate the condition of the communication  
channel is for the base station to transmit pilot signals, which are signals typically  
transmitted on a small fraction of the transmission resource and are generally  
comprised of known (pre-determined) symbols transmitted at a single constant power

level. The wireless terminal measures the pilot signals and reports to the BS in the form of a scalar ratio such as signal-to-noise ratio (SNR) or an equivalent metric. In the case where noise/interference is not dependent on the transmitted signal, e.g., background noise is predominant and the contribution from self-noise and inter-sector interference is insignificant, such a single scalar metric is sufficient for the BS to predict how the received SNR, at the wireless terminal, will change with signal transmit power. Then, the base station can determine the minimum level of transmission power required to achieve an acceptable received SNR at the wireless terminal, for the particular error-correcting coding scheme and modulation used. However, in the case where the total noise/interference includes a significant component that is dependent on signal transmission power, e.g., inter-sector interference from base station transmissions in adjacent sectors, the commonly used technique of obtaining an SNR from pilot signals of one fixed strength level is insufficient. In such a case, the information obtained, e.g., SNR at a single transmission power level, by this commonly used technique, is insufficient and inadequate for the BS to accurately predict the received SNR at the WT as a function of the signal transmit power. Additional channel quality information needs to be generated, collected by the wireless terminal, and relayed to the base station, so that the base station can solve for the wireless terminals' function relating received SNR to base station signal transmission power level. By obtaining such a function for a wireless terminal's communication channel, the base station's scheduler, knowing the acceptable level of received SNR for a particular coding rate, error-correcting code, and modulation used, could efficiently assign a wireless terminal segments in a channel with an appropriate power level, thus achieving acceptable SNR, limiting wasted transmission power, and/or reducing overall levels of interference.

Based upon the above discussion, it is clear that there is a need, particularly in the case of multi-sector wireless communications systems, for new and novel apparatus and methods of channel quality measuring, evaluating and reporting that will provide the base station with sufficient information to obtain the wireless terminal received signal SNR as a function of base station transmitted power. In addition, to support improved and/or more diverse channel quality measurements, new pilot signal

patterns, sequences and/or pilot signal transmission power levels which can facilitate the analysis of self noise and interference from other sectors of a cell are desirable.

#### SUMMARY OF THE INVENTION:

Improved pilot signal sequences which facilitate multiple channel quality measurements, e.g., through the use of different signal pilot transmission power levels, are described. In various implementations the transmitted pilot sequences facilitate determining the contribution of interference from other sectors of a cell using the same tones, e.g., in a synchronized manner, as the sector in which the pilot signal measurements are being made.

In cases where different sectors transmit on a tone at the same time using approximately the same power, signals from other sectors while being interference can be viewed as being similar or the same as self noise since transmission power affects the amount of noise that will be encountered in a sector.

To measure noise contributions from neighboring sectors a sector NULL pilot, e.g., a pilot with zero power, is transmitted in an adjacent sector at the same time a pilot signal with a pre-selected, and therefore known, non-zero power is transmitted in the sector where the received pilot signal measurement is made. To facilitate background noise measurements, a cell NULL is supported in some embodiments. In the case of a cell NULL, all sectors of a cell transmit a Null pilot, on a tone that is used to measure background noise. Since no power is transmitted in the cell on the tone during the measurement, any measured signal on the tone is attributable to noise, e.g., background noise which may include inter-cell interference.

The pilot sequences and signal measurements of the present invention provide mechanisms that enable a wireless terminal (WT), and a BS that receives channel condition feedback information from the WT, to predict downlink receive SNR for the WT as a function of the signal transmit power in the presence of signal dependent

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noise. Feedback from individual WTs, in accordance with the invention, normally includes at least two channel quality indicator values per WT, as opposed to a single SNR value, where each of the two channel quality indicator values is generated using a different function. One of the two channel quality indicator value generator functions has a first pilot signal measurement corresponding to a received pilot signal having a first known transmission power as an input. A second one of the two channel quality indicator value generator functions has as an input a second pilot signal measurement corresponding to another received pilot signal having a second known transmission power which is different from the first known transmission power. Each of the first and second channel quality indicator value generator functions, which may be implemented as software modules or as hardware circuits, may also have additional inputs to those just mentioned.

Feedback from individual WTs, including at least two channel quality indicator values per WT that are generated using different functions, enables the base station (BS) to transmit to different WTs at different, e.g., minimum, signal powers depending upon the respective SNRs required at the receivers. The total power transmitted by the BS is typically known or fixed but the proportion allocated to different WTs may be different and may vary over time. At a WT receiver, the dependence of total noise as a function of the received signal power can be modeled by a straight line; referred to as the 'noise characteristic line' in this invention. Since the noise characteristic line does not in general go through the origin, a single scalar parameter is not enough to characterize this line. At least two parameters are required to determine this line.

The base station transmits pilot signals on the downlink. In accordance with the invention, by transmitting pilot signals of different strength levels, the noise characteristic line for the wireless terminal can be determined. In general a first pilot signal is transmitted at a first power level to obtain a first point, and a second pilot signal at a second power level, different from the first power level, is transmitted to obtain a second data point. The second power level can be zero in some embodiments.

128 The above pilot signal scheme can be used in a cell using an omni-antenna, that is, a  
129 cell with only one sector.  
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131 The invention further determines SNR as a function of signal transmit power in a  
132 sectorized cellular environment. In one method of sectorization, each of the different  
133 sectors of a cell may use the entire or nearly the entire transmission resource (for  
134 example, frequency band) to transmit in each of the sectors. The total power  
135 transmitted from each sector is typically fixed or known, but different WTs may receive  
136 signal with different power. Since the isolation between the sectors is not perfect,  
137 signals transmitted on one sector may become noise (interference) to other sectors.  
138 Furthermore, if each of the sectors is constrained to transmit identical or nearly identical  
139 signal power (or to transmit signal power in a fixed proportion across the different  
140 sectors) on a given degree of freedom (e.g., time slot), the interference from other  
141 sectors to a WT in a given sector has the characteristics of signal-dependent noise or  
142 self-noise. This is particularly the case when the interference from other sectors scales  
143 with signal power which occurs in embodiment where different sectors are constrained  
144 to transmit identical or proportional power on a given degree of freedom, e.g., tones in  
145 an OFDM multiple access system.  
146

147 In accordance with the invention, regular pilots at different predetermined and  
148 known strength levels, are transmitted from the base station to the wireless terminals to  
149 characterize the dependence of total noise at a WT on the power of the signal by the  
150 BS to the WT. Different sectors may be, and often are, controlled to transmit at least  
151 some pilots on the same tone at the same time. Different sectors are often controlled to  
152 use different predetermined transmission power levels for the pilot signal transmitted on  
153 a tone in each of the sectors. For example, on tone 1 at time T1, a first sector may be  
154 controlled to transmit a pilot signal at a first power level while an adjacent sector is  
155 controlled to transmit at the same time T1, a pilot signal at a second power level on  
156 tone 1, the second power level being different from the first power level.  
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158 According to one embodiment of this invention, 'cell null pilots' are used in  
159 conjunction with regular pilots to characterize the dependence of total noise at a WT on  
160 the power of the signal transmitted by the BS to that WT. Cell null pilots are downlink  
161 resources (degrees of freedom) where none of the sectors of the cell transmit any  
162 power. Noise measured on these degrees of freedom provides an estimate of the  
163 signal-independent noise at the WT. Regular pilots (or simply pilots) are resources  
164 (degrees of freedom) where each sector of the cell transmits known symbols using  
165 fixed or predetermined powers. Noise measured on the pilots thus includes inter-sector  
166 interference and provides an estimate of the total noise, including signal-dependent  
167 noise.

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169 One feature of the invention is directed to the concept of a 'sector null pilot'. The  
170 sector null pilots can be used in a sectorized cellular wireless system to estimate the  
171 noise at the WT, for example, when the WT is at the boundary of two sectors and the  
172 scheduling between the sectors is coordinated so that the WT at the boundary does not  
173 receive any interference from the other sector. Sector null pilot can be downlink  
174 resources where one sector in a cell does not transmit any signal energy and the rest or  
175 an adjoining sector transmits regular, e.g., non-zero pilots.

176  
177 More generally, other types of sector null pilots can be defined, such as where a  
178 subset of the sectors of a cell transmits no signal on downlink resources and the  
179 remaining sectors transmit regular pilots. Also, more generally, the coordinated  
180 scheduling amongst the sectors can be such that the BS reduces (but does not  
181 necessarily eliminate) the transmit power on some sectors in order to reduce the  
182 interference that a WT receives from other sectors. In some cases, data is transmitted  
183 on a tone in an adjacent sector to a sector which transmits a pilot signal on the tone.

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185 With the help of various regular strength pilots and/or various null pilot types, a  
186 WT can estimate the noise at the receiver as a function of the power of the signal  
187 transmitted to that WT under various conditions. The invention also concerns itself with  
188 the communication of this information from the WT to the BS in order to enable the BS

189 to determine the power to be used for transmitting to the different WTs in both omni-cell  
190 and sectorized cell environments. Unlike prior art, the channel quality information is not  
191 a single scalar value but includes two or more values which can be used to reflect the  
192 effect of self noise and/or inter-sector noise in addition to background noise.

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194 In an embodiment of the invention for an OFDM based cellular wireless system  
195 the pilots include known symbols that are transmitted by the base station on specified  
196 tones (and specified symbol times) at a fixed or predetermined power, and the null  
197 pilots are typically tones that are left empty, i.e., with zero transmission power.

198  
199 In an embodiment used in an omni-directional antenna deployment, known  
200 herein as an "omni cell," the WT measures the SNR on the pilot tones, which includes  
201 all noise/interference sources, including noise that is dependent on the pilot's transmit  
202 power. In addition, the WT also measures the noise using the cell null pilot tone(s).  
203 Taking the ratio of the received pilot power with this noise measurement gives an SNR  
204 that is limited to signal-independent noise/interference. The WT transmits back to the  
205 BS these two SNR values, or some equivalent combination of statistics.

206  
207 In the embodiment of a sectorized deployment with directional sector antennas,  
208 a single cell is divided into multiple sectors, some or all of which may be sharing the  
209 same frequency band (degrees of freedom), corresponding to a frequency reuse of 1.  
210 In this situation, in addition to the cell null pilot, the invention describes the use of sector  
211 null pilots that are present in a subset of the sectors but not all sectors, and also gives a  
212 pattern for pilot tones such that a null pilot tone in one sector is time/frequency  
213 synchronized with a pilot tone in some or all of the other sectors. This allows the WT to  
214 measure two or more signal-to-noise ratios, which include interference from different  
215 combinations of sectors. On a reverse link, the WT reports a set of SNR-related  
216 statistics, which enables the BS to make an estimate of these received SNR levels at a  
217 WT as a function of the base station's transmit power. The BS uses the reported  
218 channel quality values to determine the power level at which to transmit to achieve a  
219 desired SNR at the WT.

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221 In accordance with the invention, a wireless terminal makes measurements of at  
222 least two different received pilot signals, which were transmitted at different first and  
223 second pre-selected, and thus known, power levels. The two power levels may be,  
224 e.g., a fixed non-zero power level and a transmission power level of zero although other  
225 power level combinations are possible there being no mandatory requirement that one  
226 power level be a zero power level. The value obtained from measuring the first  
227 received pilot signal is processed by a first function to produce a first channel quality  
228 indicator value. The second measured signal value obtained from measuring the  
229 second received pilot signal is processed by a second function, which is different from  
230 the first function, to produce a second channel quality indicator value. The first and  
231 second channel quality indicator values are transmitted from the wireless terminal to the  
232 base station. In some embodiments, they are transmitted in a single message while in  
233 other embodiments they are transmitted in separate messages. The channel quality  
234 indicator values may be, e.g., SNR values or power values. Thus, the first and second  
235 channel quality indicator values may both be SNR values, may both be power values,  
236 or one may be an SNR value and one a power value. Other types of values may also  
237 be used as the channel quality indicator values with SNR and power values being  
238 exemplary.

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240 In some embodiments the WT determines its location relative to a sector  
241 boundary and reports this location information to the base station. The location  
242 information is reported to the base station. The reported location information is  
243 normally in addition to the two channel quality indicator values is sometimes sent as a  
244 separate message. However, in some cases, the location information is transmitted in  
245 the same message as the two channel quality indicator values.

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247 Numerous additional features, benefits and embodiments of the methods and  
248 apparatus of the present invention are discussed in the detailed description which  
249 follows.  
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251 **BRIEF DESCRIPTION OF THE DRAWINGS:**

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Figure 1 is a simplified diagram showing a transmitter and a receiver used for explaining the present invention.

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Figure 2 shows an exemplary wireless cellular system.

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Figure 3 shows an example where noise is dependent on transmitted signal power and is used for explaining the present invention.

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Figure 4 shows an example of an exemplary noise characteristic line, showing received power vs total noise, and is used for explaining the present invention.

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Figure 5 shows a graph of power vs frequency corresponding to an exemplary embodiment of the invention illustrating data tones, non-zero pilot tones, and a null pilot tone.

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Figure 6 is a graph illustrating the relationship between SNR1, a wireless terminal received SNR including signal dependent and signal independent noise, and SNR0, a wireless terminals received SNR including no signal dependent noise for 3 cases: where noise is independent of the signal, where the signal dependent noise is equal to the signal, and where the signal dependent noise is less than the signal.

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Figure 7 shows exemplary signaling for a three sector OFDM embodiment of the invention illustrating non-zero pilot tones, sector null pilot tones, and cell null pilot tones in accordance with the invention.

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Figure 8 illustrates an example of tone hopping of the non-zero pilots, sector null pilot, and cell null pilots in accordance with the invention.

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Figure 9 illustrates three situations for an exemplary wireless terminal in a 3 sector embodiment used to explain the present invention in regard to the sector boundary information aspects of the present invention.

Figure 10 illustrates a scheme using 3 sector types, which are repeated for the cases with cells involving more than 3 sectors in accordance with the present invention.

Figure 11 illustrates an exemplary communications systems implementing the present invention.

Figure 12 illustrates an exemplary base station implemented in accordance with the present invention.

Figure 13 illustrates an exemplary wireless terminal implemented in accordance with the present invention.

Figure 14 illustrates the steps of transmitting pilot tones in multiple sectors of a cell in a synchronized manner in accordance with the present invention.

Figures 15-17 illustrate exemplary pilot tone transmissions along with pilot signal transmission power information in accordance with the present invention.

Figure 18 illustrates a chart showing the transmission of signals on ten different tones during a single symbol transmission period in accordance with the present invention.

Figure 19 is a flowchart illustrating the operation of an exemplary wireless terminal implementing the methods of the present invention.

Figure 20 is a flowchart illustrating the operation of an exemplary base station implementing the methods of the present invention.

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313 DETAILED DESCRIPTION:

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315 The methods and apparatus of the present invention are well suited for use in a  
316 wireless communications system which uses one or more multi-sector cells. Figure 11  
317 illustrates an exemplary system 1100 with a single cell 1104 shown but it is to be  
318 understood that the system may, and often does, include many of such cells 1104.  
319 Each cell 1104 is divided into a plurality of N sectors wherein N is a positive integer  
320 greater than 1. System 1100 illustrates the case where each cell 1104 is subdivided  
321 into 3 sectors: a first sector S0 1106, a second sector S1 1108, and a third sector S2  
322 1110. Cell 1104 includes a S0/S1 sector boundary 1150, a S1/S2 sector boundary  
323 1152, and a S2/S0 sector boundary 1154. Sector boundaries are boundaries where the  
324 signals from multiple sectors, e.g., adjoining sectors, may be received at almost the  
325 same level making it difficult for a receiver to distinguish between transmissions from  
326 the sector in which it is located and the adjoining sector. In the cell 1104, multiple end  
327 nodes (ENs), e.g., wireless terminals (WTs), such as mobile nodes, communicate with  
328 a base station (BS) 1102. Cells with two sectors (N=2) and more than 3 sectors (N>3)  
329 are also possible. In sector S0 1106, a plurality of end nodes EN(1) 1116, EN (X) 1118  
330 are coupled to base station 1 1102 via wireless links 1117, 1119, respectively. In  
331 sector S1 1108, a plurality of end nodes EN(1') 1120, EN (X') 1122 are coupled to base  
332 station 1 1102 via wireless links 1121, 1123, respectively. In sector S2 1110, a plurality  
333 of end nodes EN(1'') 1124, EN (X'') 1126 are coupled to base station 1 1102 via  
334 wireless links 1125, 1127, respectively. In accordance with the invention, the base  
335 station 1102 transmits pilot signals at multiple power levels to the ENs 1116, 1118,  
336 1120, 1122, 1124, 1126, and there is synchronization of the transmission of pilot  
337 signals of various predetermined and known levels between the three sectors. In  
338 accordance with the invention, the end nodes, e.g., EN(1) 1116 report feedback  
339 information, e.g., channel quality indicator values to the base station 1102, allowing the  
340 base station 1102 to determine the wireless terminals received SNR as a function of  
341 base station transmitted signal power. Base station 1102 is coupled to a network node  
342 1112 via network link 1114. The network node 1112 is coupled to other network nodes,  
343 e.g., intermediate nodes, other base station, AAA nodes, home agent nodes, etc., and

the internet via network link 1129. Network node 1112 provides an interface outside cell 1104, so that ENs operating within the cell may communicate with peer nodes outside the cell 1104. The ENs within cell 1104 may move within the sectors 1106, 1108, 1110 of the cell 1104 or may move to another cell corresponding to another base station. Network links 1114 and 1129, maybe, e.g., fiber optic cables.

Fig. 12 illustrates an exemplary base station (BS) 1200, implemented in accordance with the invention. Base station 1200 is a more detailed representation of base station 1102 shown in the exemplary communication system 1100 of Figure 11. The base station 1200 includes sectorized antennas 1203, 1205 coupled to receiver 1202 and transmitter 1204, respectively. The receiver 1202 includes a decoder 1212 while the transmitter 1204 includes an encoder 1214. Base station 1200 also includes an I/O interface 1208, a processor, e.g., CPU, 1206 and memory 1210. The transmitter 1204 is used to transmit pilot signals into multiple sectors in a synchronized manner via sectorized transmit antenna 1205. The receiver 1202, the transmitter 1204, the processor 1206, the I/O interface 1208, and the memory 1210 are couple together via bus 1209 over which the various elements can interchange data and information. The I/O interface 1208 couples the base station 1200 to the Internet and to other network nodes.

The memory 1210 includes routines 1218 and data/ information 1220. Routines 1218, which when executed by the processor 1206, cause the base station 1200 to operate in accordance with the invention. Routines 1218 include communications routine 1222, a received signal processing routine 1260, and base station control routines 1224. The received signal processing routine 1260 includes a channel quality indicator value extraction module 1262 which extracts channel quality indicator values from received signals, e.g., WT report messages, and a position information extraction module 1264 for extracting WT position information from received messages. The position information, in some embodiments, indicates a WT's position relative to a sector boundary. Extracted channel quality indicator values, e.g., SNR or power values, are provided to the transmission power calculation routine 1226 for use in

375 calculating transmission power for signals transmitted to a WT. The base station  
376 control routines 1224 include a scheduler module 1225, a transmission power  
377 calculation routine 1226, and signaling routines 1228 including a pilot signal generation  
378 and transmission control routine.

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380 The data/information 1220 includes data 1232, pilot hopping sequence  
381 information 1234, and wireless terminal data / information 1240. Data 1232 may  
382 include data from the receiver's decoder 1212, data to be sent to the transmitter's  
383 encoder 1214, results of intermediate processing steps, etc. The pilot hopping  
384 sequence information 1234 includes power level information 1236 and tone information  
385 1238. The power level information defines the different power levels that will be applied  
386 to different tones in order to generate pilots of various strengths, within the pilot tone  
387 hopping sequence in accordance with the invention. These pilot values are set e.g.,  
388 preselected fixed values, prior to transmission and are known to both the BS 1200 and  
389 WTs in the cell serviced by the BS 1200. Tone info 1238, includes information defining  
390 which tones shall be used as pilot tones of a specific strength level, which tones shall  
391 be sector null tones, and which tones shall be cell null tones, within the pilot tone  
392 hopping sequence for each sector for each terminal ID 1246. Wireless terminal  
393 data/information 1240 includes sets of data information for each wireless terminal  
394 operating within the cell, WT 1 info 1242, WT N info 1254. Each set of info, e.g., WT1  
395 info 1242 includes data 1244, terminal ID 1246, sector ID 1248, channel quality  
396 indicator values 1250, and sector boundary position info 1252. Data 1244 includes  
397 user data received from WT 1 and user data to be transmitted to a peer node  
398 communicating with WT 1. Terminal ID 1246 is a base station assigned Identification  
399 that has been assigned to WT 1; a specific pilot tone hopping sequence, including  
400 various strength pilot signals at predetermined times, is generated by the base station  
401 corresponding to each specific terminal ID 1246.

402  
403 The sector ID 1248 identifies which of the three sectors, S0, S1, S2, WT 1 is  
404 operating in. The channel quality indicator values 1250 include information conveyed  
405 by WT 1 to the base station in channel quality report messages, that the base station

may use to calculate the expected received WT1 SNR level as a function of base station transmission signal power. The channel quality indicator values 1250 are derived by WT1 from measurements performed by WT1 on the various strength pilot signals transmitted by the base station, in accordance with the present invention. The sector boundary position information 1252 includes: information identifying whether WT1 has detected that it is near a sector boundary, experiencing high levels of interference and information identifying which sector boundary WT1 is located near. This information is obtained or derived from position feedback information transmitted by the WT1 and received by the BS. The channel quality indicator values 1250 and the sector boundary position information 1252 represent channel quality feedback information from the WT1 to the base station 1200, providing information about one or more downlink channels between the base station 1200 and WT1.

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Communications routines 1222 is used for controlling the base station 1200 to perform various communications operations and implement various communications protocols. Base station control routines 1224 used to control the base station 1200 to perform basic base station functionality, e.g., signal generation and reception, scheduling, and to implement the steps of the method of the present invention including generation of pilot signals at different transmission strength levels, reception and processing and use of wireless terminal reported information. The signaling routine 1228 controls the transmitter 1204 and the receiver 1204 which generate and detect signals to and from the wireless terminals, e.g. OFDM signals following data tone hopping sequences. Pilot signal generation and transmission control routine uses the data/ information 1220 including the pilot hopping sequence info 1234 to generate a specific pilot tone hopping sequences for each sector. The power levels of the pilot tones, included in power level info 1236 and the specific tones selected to receive specific pilot tones for each pilot in each sector at specific times are coordinated and controlled under the direction of the pilot signal generation and transmission control routine 1230. This routine 1230 controls the transmission of pilot tones, e.g., as illustrated in Figs 15-17. Individual processing instructions, e.g., software commands, responsible for the transmission of different pilot tones are individual components or

modules which may be interpreted as separate means which operate together to control the base station to transmit the pilot tone sequences described and shown in Figs. 15-17. Coordinating and/or synchronizing the transmission of various types of pilot signals between the sectors of a cell, e.g., in terms of transmission frequency, and/or symbol transmission time while controlling transmission power, enables a wireless terminal receiving the various levels of transmitted pilot tones, e.g., known predetermined fixed level pilot tones, sector null pilot tones, and cell null pilot tones, to obtain, e.g., compute from measured signal values, channel quality indicator values 1250. In accordance with the invention, regular (non-null) pilot tones, sector null pilot tones, and cell null pilot tones may punch through or replace data tones that would normally be transmitted. Scheduling module 1225 is used to control transmission scheduling and/or communication resource allocation. The scheduler 1225, in accordance with the invention, may be supplied with information indicating each wireless terminal's received SNR as a function of the base station transmitted signal power. Such information, derived from the channel quality indicator values 1250, may be used by the scheduler to allocate channel segments to WTs. This allows the BS 1200 to allocate segments on channels having sufficient transmission power to meet received SNR requirements for a particular data rate, coding scheme, and/or modulation selected to be provided to a WT.

Figure 13 illustrates an exemplary wireless terminal 1300 implemented in accordance with the present invention. The wireless terminal 1300 may be used as a wireless end node, e.g., a mobile node. Wireless terminal 1300 is a more detailed representation of the ENs 1114, 1116, 1118, 1120, 1122, 1124 shown in the exemplary communications system 1100 of Figure 11. Wireless terminal 1300 includes a receiver 1302, a transmitter 1304, a processor, e.g., CPU, 1306, and memory 1308 coupled together via a bus 1310 over which the elements may interchange data and information. The wireless terminal 1300 includes receiver and transmitter antennas 1303, 1305 which are coupled to receiver and transmitter 1302, 1304 respectively. The receiver 1302 includes a decoder 1312 while the transmitter 1304 includes an encoder 1314. Processor 1306, under control of one or more routines 1320 stored in memory



468 1308 causes the wireless terminal 1300 to operate in accordance with the methods of  
469 the present invention as described herein. Memory 1308 includes routines 1320 and  
470 data/information 1322. Routines 1320 includes communications routine 1324 and  
471 wireless terminal control routines 1326. The wireless terminal control routines 1326  
472 includes signaling routine 1328 including a pilot signal measuring module 1330, a  
473 channel quality indicator value generating module 1332, a sector boundary position  
474 determining module 1331, and a channel quality indicator value transmission control  
475 module 1333. Data/information 1322 includes user data 1334, e.g. information to be  
476 transmitted from the wireless terminal 1300 to a peer node, user info 1336, and pilot  
477 signaling info 1350. User info 1336 includes measured signal values info 1337, quality  
478 indicator value information 1338, sector boundary position information 1340, terminal ID  
479 information 1342, base station ID information, and channel report information 1346.  
480 Pilot signaling info 1350 includes hopping sequence info 1352, power level info 1354,  
481 and tone info 1356. The measured signal value info 1337 includes measured signal  
482 values obtained from measurements, performed under the control of pilot signal  
483 measuring module 1330, of a at least one of an amplitude and phase of a received pilot  
484 signal. The quality indicator value information 1338 includes output from the channel  
485 quality indicator value generating module 1332. The channel quality indicator value  
486 information 1338, when transmitted to a base station may allow the base station to  
487 determine the WTs received SNR as a function of transmitted signal power. Sector  
488 boundary position information 1340 includes information identifying that the wireless  
489 terminal is in a sector boundary region, e.g., the wireless terminal is experiencing high  
490 inter-sector interference levels, and information identifying which of the two adjacent  
491 sectors is the boundary region sector. The base station may use the sector boundary  
492 information to identify channels in adjacent sectors where the transmission power  
493 should be turned off to reduce inter-sector interference. Channel report information  
494 1346 includes the quality channel indicator values 1338 obtained or portions of the  
495 channel quality indicator values 1338 and may also include sector boundary position  
496 information 1340. The channel report information 1346 may be structured with  
497 individual messages for each quality indicator value or with groups of quality indicator  
498 values included in a single message. The messages may be sent out periodically at

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predetermined times on dedicated channels. The terminal ID information 1342 represents a base station assigned identification applied to the wireless terminal 1300 while operating within the cellular coverage area of the base station. The base station ID info 1344 includes information specific to the base station, e.g., a slope value in a hopping sequence, and may also include sector identification information.

The pilot hopping sequence information 1352 identifies for a given base station, with base station ID info 1344, which tones 1356 at what time, e.g., OFDM symbol time, should be measured to evaluate pilot signals. The pilot signal power level information 1354 identifies to the wireless terminals, the transmission levels of pilot signals on the assigned pilot signal tones 1356 included in the pilot tone hopping sequence 1352. Pilot signal power level information 1354 may also identify sector and cell null pilot tones.

Communications routines 1324 is used for controlling the wireless terminal 1300 to perform various communications operations and implement various communications protocols.

Wireless terminal control routines 1326 controls the basic functionality of the wireless terminal 1300 in accordance with the methods of the present invention. Wireless terminal signaling routines 1328 control the basic functionality of the wireless terminal signaling including control of the receiver 1302, transmitter 1304, signal generation and reception and controls the operation of the wireless terminal in accordance with the methods of the present invention including the measuring of pilot signals, the generation of quality indicator values, and the transmission of channel quality indicator values. The pilot signal measuring module 1330 controls the measurement of received pilot signals, identified by the base station ID info 1344, hopping sequence info 1352, and tone info 1356. Pilot signal measuring routine 1330 measures at least one of an amplitude and a phase of a pilot signal to produce a measured signal value corresponding to each pilot signal measured. Channel quality indicator value generating module 1332 includes a power estimation module 1361 and

530 a SNR estimation module 1362. Channel quality indicator value generating module  
531 1332 generates quality indicator values according to functions, which use the measured  
532 signal values 1337 output from the pilot signal measuring module 1330. Module 1332  
533 includes first and second sets of instructions for implementing first and second channel  
534 quality indicator value functions where the first and second functions are different.  
535 Power estimation module 1361 includes software instructions for controlling the  
536 processor 1306 to estimate the received power included in received pilot signal(s). SNR  
537 estimation module 1362 includes software instructions for controlling the processor  
538 1306 to estimate the signal to noise ratio of received pilot signal(s). The sector  
539 boundary position determining module 1331 determines the position of the wireless  
540 terminal 1300 relative to a sector boundary from information included in received  
541 signals. The sector boundary position determining module 1331 may also distinguish  
542 which adjacent sector boundary the wireless terminal is closer to and which adjacent  
543 sector is causing higher interference levels with respect to WT 1300. The information  
544 output from sector boundary position determining module 1131 is included in the sector  
545 boundary position information 1340. The channel quality indicator value transmission  
546 control routine 1333 controls the transmission of the quality channel value indicator  
547 information and sector boundary information to the base station. The channel quality  
548 indicator value transmission control routine 1333 includes a message generation  
549 module 1335. Message generation module 1335 controls the processor 1306 using  
550 machine executable instructions to generate messages used to communicate channel  
551 quality indicator values. Message generation module 1335 may generate messages  
552 with a single channel quality indicator value or include at least two channel quality  
553 indicator values in a single message. Message generation module 1335 may also  
554 generate messages, which include position information, e.g., sector boundary position  
555 information 1340 or incorporate such information into a message which includes a  
556 channel quality indicator value. The messages, generated by message generation  
557 module 1335 are transmitted under control of the channel quality indicator value  
558 transmission control module 1333. Messages corresponding to first and second values  
559 may be interleaved, e.g., alternated for transmission purposes. Channel quality  
560 indicator value transmission control module 1333 transmits messages periodically in

some embodiments using communication channel segments dedicated to carrying channel quality indicator values. Module 1333 may also control the transmission times to correspond to pre-selected dedicated time slots dedicated by the base station for use by a WT 1300 thereby precluding other wireless terminals from using the dedicated time slots.

Figure 1 is a simplified diagram showing a transmitter 101 and a receiver 103 which will be used for explaining the invention. Transmitter 101 may be, e.g., the transmitter 1204 of base station 1200, while receiver 103 may be, e.g., the receiver 1302 of wireless terminal 1300. In a communications system, such as the system 1100, the transmitter 101 often needs to make choices about the appropriate method for transmitting data to the receiver 103. The choices may include the code rate of the error-correcting code, the modulation constellation, and the transmit power level. In general, in order to make sensible choices, it is desirable for the transmitter 101 to have knowledge about the communication channel from the transmitter 101 to the receiver 103. Figure 1 shows an exemplary system 100, in which a transmitter 101 sends data traffic 104 to a receiver 103 on a forward link 105. On a reverse link 107 from the receiver 103 to the transmitter 101, the receiver 103 reports the forward link's channel condition 106 to the transmitter 101. The transmitter 101 then uses the reported channel condition information 106 to set its parameters properly for transmission.

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Figure 2 shows an exemplary wireless cellular system 200 where a transmitter is included in a base station (BS) 201 with antenna 205 and a receiver is included in a wireless terminal (WT), 203, e.g., a mobile terminal or a fixed terminal, with antenna 207, enabling the base station 201 to communicate information on the downlink channel(s) 208 to the wireless terminal 203. The BS 201 often transmits pilot signals 209, which are typically transmitted on a small fraction of the transmission resource and are generally comprised of known (pre-determined) symbols transmitted at a constant power. The WT 203 measures the downlink channel condition 213 based on the received pilot signals 209, and reports the channel conditions 213 to the BS 201 on an uplink channel 215. Note that since the channel conditions 213 often change over time

due to fading and Doppler effects, it is desirable that the BS 201 transmit the pilots 209 frequently or even continuously so that the WT 203 can track and report channel conditions 213 as they vary with time. The WT 203 can evaluate the downlink channel conditions 213 based on the received signal strength and the noise and interference on the pilot signals 209. The combination of noise and interference will be referred to subsequently as 'noise/interference' or sometimes just 'noise'. In the prior art techniques, this type of information is normally reported in the form of a single scalar ratio such as signal-to-noise ratio (SNR) or an equivalent metric. In the case where noise/interference is not dependent on the transmitted signal, such a single scalar metric is usually all that is required at the BS 201 to predict how the received SNR will change with signal transmit power. In such a case, the BS 201 can determine the correct (minimum) transmit power for the coding and modulation it selects to transmit from the single received value. Unfortunately, in the multi-sector case, noise resulting from transmitted signals can be a significant signal component making a single scalar value insufficient for accurate SNR predictions for different transmission power levels.

In many communication situations, especially in cellular wireless systems, such as the multi-sector system 1100 of the invention, the noise is not independent of the signal transmit power but depends on it. There is generally a component of noise called 'self-noise', which is proportional or roughly proportional to the power of the signal. Figure 3, shows an example where noise is dependent on signal transmit power. In Figure 3, graph 300 shows received power of the signal of interest on the vertical axis 301 vs total noise on the horizontal axis 303. Total noise, represented by line 305 which is the sum of a signal dependent portion 309 and a signal independent portion 307, is plotted against the received signal power 317. There may be many reasons for the self-noise. An example of self-noise is the unequalized signal energy that interferes with the received signal. This noise is proportional to the signal strength. The unequalized signal energy could result from error in channel estimation or error in the equalizer coefficients or from many other reasons. In situations where the self-noise is comparable to or larger than the signal-independent noise, a single scalar downlink SNR value (which may be measured on a pilot) is no longer adequate for the

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623 BS 1200 to accurately predict the received SNR at the WT 1300 as a function of the  
624 signal transmit power.

625  
626 This invention provides a methods and apparatus which enable each WT 1300  
627 to predict its downlink receive SNR as a function of the signal transmit power in the  
628 presence of signal dependent noise 309 and communicate this information to the BS  
629 1200. This enables the BS 1200 to transmit to different WTs at different (minimum)  
630 signal powers depending upon the respective SNRs required at each of the WTs. The  
631 total power transmitted by the BS 1200 is typically known or fixed but the proportion  
632 allocated to different WTs 1300 may be different and may vary over time. At a WT  
633 receiver 1302, the dependence of total noise 303 as a function of the received signal  
634 power 317 can be modeled by a straight line 305, referred to as the 'noise characteristic  
635 line' in this application, as shown in Figure 3. Since the noise characteristic line 305  
636 does not in general go through the origin, a single scalar parameter is not enough to  
637 characterize this line 305. At least two parameters, e.g., two channel quality indicator  
638 values, are required to determine this line 305. A simple method of determining this  
639 line is to identify the location of two distinct points, e.g., points 311 and 315, on it, since  
640 any two distinct points uniquely determine a straight line. Note that as a practical  
641 matter, the points can be determined with a limited accuracy, so that the accuracy with  
642 which the line is determined is better if the points are chosen farther apart than if the  
643 points are closer together.

644  
645 The base station 1200 transmits pilot signals on the downlink. In accordance  
646 with the invention, by transmitting pilot signals of different strength levels, the noise  
647 characteristic line for the wireless terminal can be determined. In general a first pilot  
648 signal is transmitted at a first power level to obtain a first point, and a second pilot  
649 signal at a second power level, different from the first power level, is transmitted to  
650 obtain a second data point. The first and second pilots can be transmitted at the same  
651 time if different tones are used for each pilot signal.

652

With respect to figure 3, the first pilot signal is measured and processed to produce the first point 315 on line 305 identifying received pilot power level 317 and a corresponding total noise level 319. In accordance with an embodiment of the invention, the BS 1200 transmits 'null pilot' signals on the downlink in addition to non-zero pilots. The null pilots are comprised of transmission resources (degrees of freedom) where the BS 1200 transmits no signal power, e.g., transmits a pilot signal having zero power. The second pilot signal, the null pilot signal, results in point 311 on line 305 and identifies null pilot noise level 313 which is equivalent to the signal independent noise 307. Based on the noise measured on both, the pilots and the null pilots the WT 1300 obtains two different noise estimates 313, 315 at two different signal powers, e.g., 0 power and received pilot power 317. From these two points 311, 315, the WT 1300 can determine the entire noise characteristic line 305 of Figure 3. The WT 1300 can then also communicate the parameters of this line 305 (for example, slope and intercept, or some other equivalent set of information) to the BS 1200 enabling the BS 1200 to determine the received SNR for a given transmit signal power when transmitting to the WT 1300 which reported multiple channel quality values. Since null pilots have zero signal power and other pilots, on the other hand, are usually transmitted at a relatively large power, the two points 311, 315 corresponding to the null pilot and the non-zero pilot in Figure 3 are relatively far apart leading to a good accuracy in characterizing the line 305.

Signal noise and various signaling issues will now be discussed further. Graph 400 of Figure 4 plots received power of a signal of interest on the vertical axis 401 vs total noise on the horizontal axis 403. Figure 4 gives an illustration of an exemplary noise characteristic line 405. To characterize the line 405, in accordance with the invention, the BS 1200 transmits signals that enable the WT 1300 to make measurements of at least two distinct points on the line, e.g. points 407 and 409, information, characterizing the line 405, obtained from those measurements is then transmitted to the BS 1200. For example, the BS 1200 can transmit two different signal powers  $P_1$  and  $P_2$  that will be received as powers  $Y_1$  and  $Y_2$  as shown in Figure 4. The WT 1300 measures the corresponding received signal powers, denoted as  $Y_1$  and  $Y_2$ .

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684 and  $Y_2$  419, and the corresponding total noise, denoted as  $X_1$  413 and  $X_2$  417,  
 685 respectively. From  $X_1$  413,  $X_2$  417,  $Y_1$  415, and  $Y_2$  419, the slope and the intercept of  
 686 the line 405 can be uniquely determined. In one embodiment,  $P_1$  and  $P_2$  are known  
 687 and fixed. In another embodiment,  $P_2$  can be the pilot power, corresponding to a pilot  
 688 signal, while  $P_1$  can be zero, representing a null signal, which occupies some  
 689 transmission resource but with zero transmission power. In general, however,  $P_1$  does  
 690 not necessarily have to be zero. For example,  $P_1$  can and in some embodiments is  
 691 some positive number smaller than  $P_2$ .

692  
 693 Once the noise characteristic line 405 has been determined by the BS 1200 from  
 694 received feedback information, the BS 1200 can calculate the SNR at the WT receiver  
 695 1302 for any given transmission power  $Q$ . For example, Figure 4 shows the procedure  
 696 of determining the SNR corresponding to a given transmission power  $Q$ . First, the BS  
 697 1200 finds the corresponding received signal power  $Y$  421 of transmission power  $Q$ , by  
 698 linearly interpolating between the points  $(Y_2, P_2)$  and  $(Y_1, P_1)$ :

$$Y = Y_1 + \frac{Y_2 - Y_1}{P_2 - P_1} \cdot (Q - P_1).$$

702 The corresponding noise power corresponding to a transmission power  $Q$  is given by  
 703 linearly interpolating between the points  $(X_2, P_2)$  and  $(X_1, P_1)$ :

$$X = X_1 + \frac{X_2 - X_1}{P_2 - P_1} \cdot (Q - P_1)$$

707 Then  $SNR(Q)$ , the SNR as seen by the WT 1300 for a BS transmit power  $Q$ , is given  
 708 by:

$$SNR(Q) = \frac{Y}{X} = \frac{Y_1(P_2 - P_1) + (Y_2 - Y_1)(Q - P_1)}{X_1(P_2 - P_1) + (X_2 - X_1)(Q - P_1)}$$

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Point A 411 on the noise characteristic line 405 shown in Figure 4 has the x-axis value of  $X$  420 and y-axis value of  $Y$  421 and corresponds to transmission power  $Q$ . Note the slope of a line that connects point A 411 and the origin 422 is  $SNR(Q)$ , the SNR at the WT receiver 1302 if transmit power  $Q$  is used. Therefore, from the noise characteristic line 405 generated from the reported statistics from the WT 1300, the BS 1200 can and does determine, for example, what transmission power is required to meet a given SNR requirement for the WT 1300.

Figure 5 shows a graph 500 plotting power on the vertical axis 501 vs frequency on the horizontal axis 503. Figure 5 corresponds to one exemplary embodiment of this invention, in which the wireless cellular network uses Orthogonal Frequency Division Modulation (OFDM). In this exemplary case, the frequency 505 is divided into 31 orthogonal tones, such that transmissions on different tones do not interfere with each other at the receiver, even in the presence of multipath fading in the channel. The minimum unit of signal transmission is a single tone in an OFDM symbol, which corresponds to a combination of time and frequency resources.

Figure 5 shows the power profile of the tones at a given OFDM symbol. In this embodiment, a pilot 515 is a known symbol sent at a fixed pilot power 507 on a tone, and the null pilot 513 is a tone with zero transmission power. These pilot tones 515 and null pilot tones 513 may hop over time, meaning that from one OFDM symbol to the next, the position that they occupy may vary. Over extended periods of time, the pilot signal transmissions are periodic due to the repetition of the hopping sequences. Four pilot tones 515 and one null pilot tone 513 are shown in Figure 5. The tone locations of the pilots 515 and the null pilots 513 are known to both the BS 1200 and the WT 1300. Twenty-six data tones 511 are also shown in Figure 5 with corresponding transmission power level 509. Figure 5 illustrates that the pilot tone transmission power level 515 is significantly higher than the data tone transmission power level 509, allowing the wireless terminals to easily recognize pilot tones. In general, the data tone transmission power 509 may not necessarily be the same across all the data tones as shown in Figure 5, but level 509 may vary from data tone to data tone.

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743  
744 In the situation of a wireless deployment situation deployed with omni-directional  
745 antennas, the embodiment specifies a single null pilot known as the cell null pilot.  
746 Suppose that a pilot tone is transmitted at power  $P_p$  and a tone carrying data traffic 211  
747 is transmitted at power  $Q$ , as indicated in Figure 5. By looking at the received signal for  
748 the pilot, the WT 1300 is able to measure the SNR, which we refer to as  $SNR(P)$ . The  
749 goal is for the base station 1200 to be able to obtain an estimate of  $SNR(Q)$ , which is  
750 the SNR as seen by the wireless terminal 1300 corresponding to the base station's  
751 transmission of data at power  $Q$ , which may be different from  $P_p$ .

752  
753 The knowledge of the received SNR is important since it determines the  
754 combination of coding rates and modulation constellations that can be supported. For a  
755 specified target block error rate (e. g., the probability that the transmission of a single  
756 codeword is incorrect) and for each coding rate and modulation constellation, it is  
757 possible to define a minimum SNR that the received SNR must exceed in order for the  
758 probability of unsuccessful transmission to be less than the specified target rate (e.g.,  
759 1% block error rate). From this point of view, it is desirable for the BS 1200 be able to  
760 accurately estimate  $SNR(Q)$  in order to solve for the transmit power  $Q$  that will produce  
761 an SNR that exceeds the minimum SNR for the desired code rate and modulation  
762 constellation.

763  
764 The relationship between  $SNR(Q)$  and  $Q$  depends on the signal-dependent  
765 noise. For the sake of description, we assume that the signal-dependent noise is  
766 proportional to the transmit power and use the noise characteristic line 305, 405 as  
767 shown in Figures 3 and 4 to characterize the dependence of the total noise as a  
768 function of the received signal power. The principle can similarly be extended to other  
769 situations.

770  
771 Let  $\alpha$  denote the channel gain, so that when the BS transmits at power  $P_p$ , the  
772 received power by wireless terminal is  $\alpha P_p$ . Let  $N_i$  denote the signal-independent noise,

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and  $\gamma P$  represent the signal-dependent noise, where  $\gamma$  is the proportionality factor to the transmit power  $P$ . Then when measuring the SNR on pilot tones, the WT 1300 measures an SNR of

$$SNR1(P) = \frac{\alpha P}{N + \gamma P},$$

where  $P$  is the constant transmit power of the pilots and  $N$  is the signal-independent noise seen by the WT 1300. We call this 'SNR1' to indicate that it treats the signal-dependent interference as a single entity.

By using the null pilot, it is possible for the WT 1300 to separately measure the signal-independent noise  $N$ , since there is no power transmitted by the BS 1200 on this null tone. By comparing this signal-independent noise  $N$  with the received power  $\alpha P$  of the BS pilot, it is possible to estimate an SNR that is free of signal-dependent noise. Let

us represent this ratio by  $SNR0(P) = \frac{\alpha P}{N}$ , where the name 'SNR0' indicates that it

considers no signal-dependent noise. Then the relationship between  $SNR1(P)$  and  $SNR0(P)$  is given by:

$$\frac{1}{SNR1(P)} = \frac{1}{SNR0(P)} + \frac{\gamma}{\alpha}.$$

For notational simplicity, let us define

$$SRR1 = \frac{\gamma}{\alpha}.$$

Comparing with the noise characteristic line shown in Figures 3 and 4, one can see that  $SNR0(P)$  corresponds to the x-axis intercept of the line, while  $SRR1$  is equivalent to the slope of the line. Then as a function of  $SNR0(P)$  and  $SRR1$ , we can write:

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$$SNR1(P) = \frac{SNR0(P)}{SRR1 \cdot SNR0(P) + 1}$$

In an embodiment, the measurements  $SNR0(P)$  and the  $SRR1$  are reported by the WT 1300 to the BS 1200. From these reports, the BS 1200 can compute  $SNR1(P)$ .

Graph 600 of Figure 6 illustrates the relationship between  $SNR1(P)$  on the vertical axis 601 and  $SNR0(P)$  on the horizontal axis 603, where the SNRs are plotted in dB. Three curves illustrated by lines 605, 607, and 609 representing  $SRR1=0$ ,  $SRR1=0.5$  and  $SRR1=1$ , respectively. The case of  $SRR1=0$  (line 605) corresponds to the situation where noise is independent of the signal, so that  $SNR1(P)=SNR0(P)$ . The case of  $SRR1=1$  (line 609) corresponds to the case where the signal-dependent noise is equal to the signal so that it is never possible for  $SNR1(P)$  to exceed 0 dB.

From the information received from the WT 1300, the BS 1200 can then compute the received SNR as a function of the transmit power  $Q$  for the data traffic. The received SNR by the WT 1300 will include signal-dependent noise, and takes the form

$$SNR1(Q) = \frac{\alpha Q}{N + \gamma Q}$$

Inverting and performing substitutions gives:

$$\frac{1}{SNR1(Q)} = \frac{N}{\alpha Q} + \frac{\gamma}{\alpha} = \frac{1}{SNR0(P)} \frac{P}{Q} + SRR1$$

$$SNR1(Q) = \frac{SNR0(P)}{SNR0(P) \cdot SRR1 + \frac{P}{Q}}$$

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825       Hence as a function of the values  $SNR_0(P)$  and  $SRR_1$  reported by the WT 1300,  
826 it is possible to predict the SNR as seen by the WT 1300 for any transmit power  $Q$ .  
827 These derivations illustrate that using the null pilot, the WT 1300 can determine and  
828 transmit statistics to the BS 1200 which enable the BS 1200 to predict SNR as a  
829 function of transmit power in the presence of signal-dependent noise that is proportional  
830 to the transmit power.

831  
832       Note that rather than sending  $SNR_0(P)$  and  $SRR_1$ , there are other equivalent  
833 sets of reports that the WT 1300 can send to the BS 1200, which fall within the scope of  
834 the invention.

835  
836       The methods and apparatus of the present invention are particularly useful in a  
837 multi-sector cell. In wireless cellular systems, base stations 1200 are often deployed in  
838 a configuration where each cell is divided into multiple sectors as shown in Figure 11.  
839 For a sectorized environment, the interference between sectors 1106, 1108, 1110 has a  
840 significant impact on the received SNR. In addition to the signal-independent portion,  
841 the total noise also includes signal-dependent portions, each of which is proportional to  
842 the signal power from other sectors of the same cell 1104. The noise characteristics in  
843 this case are more complex than what is shown in Figure 3, because in this sectorized  
844 situation, the total noise includes two or more signal-dependent components instead of  
845 one. However, the total noise can still be characterized by a straight line, which is now  
846 defined in a higher dimensional space. This noise characteristic line can be described,  
847 for example, by an intercept and slopes. The intercept is a function of the signal-  
848 independent noise portion and each slope corresponds to the proportionality of the  
849 signal-dependent noise portion with respect to a particular signal power.

850  
851       In certain scenarios, however, the description of the noise characteristic line can  
852 be simplified. For example, in an exemplary method of sectorization, where the each of  
853 the sectors of a cell may use the entire or nearly the entire transmission resource, e.g.,  
854 frequency band, to transmit in each of the sectors. The total power transmitted from  
855 each sector is typically fixed or known but different WTs 1300 may receive a different

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fraction of it. Since the isolation between the sectors is not perfect, signal transmitted on one sector becomes noise (interference) to other sectors. Furthermore, if each of the sectors 1106, 1108, 1110 is constrained to transmit identical, proportional or nearly proportional signal power on a given degree of freedom, the interference from other sectors to a WT 1300 in a given sector 1106, 1108, 1110 appears like signal dependent noise or self-noise. This is the case because the interference from other sectors scales with signal power, so that the noise characteristic line is similar to what is shown in Figure 3.

In accordance with the invention, the BS 1200 transmits signals such as the 'cell null pilot' that enable the WT 1300 to evaluate the intercept of the noise characteristic line with all of the signal-independent noise. In addition, as an example, the scheduling amongst the sectors 1106, 1108, 1110 may be coordinated so that WTs 1300 at the boundary 1150, 1152, 1154 of sectors do not receive any interference (or receive reduced interference) from other sectors. In accordance with the invention, the BS 1200 transmits signals such as the 'sector null pilot' that enable the WT 1300 to evaluate the slope of the noise characteristic line taking into account only the signal-dependent noise from a subset of sectors. In accordance with the invention, the WT 1300 then reports the signal-independent SNR and these different slopes, or some equivalent set of information, back to the BS 1200 on a reverse link.

Figure 7 shows in diagram 700 the signaling for an embodiment of the invention in the case of a sectorized cellular wireless system using Orthogonal Frequency Division Modulation (OFDM). Consider a BS 1200 with three sectors 701, 703, 705, in which the same carrier frequency is reused in all sectors 701, 703, 705. The pilot power level corresponding to sectors 701, 703, 705 are indicated by reference numbers 709, 713 and 717, respectively. Data signal power levels are indicated by reference numbers 711, 715, 719 for each of the first through third sectors, respectively. The situation of other numbers of sectors will be discussed below. Let the three sectors 1106, 1108, 1110 of the base station 1200 be represented by S0 701, S1 703, and S2 705 as shown in Figure 7. Figure 7 shows a tone allocation for the downlink

887 transmission at a given OFDM symbol 707, including an example of the placement of  
888 data tones, e.g. exemplary data tone 728, pilot tones, e.g. exemplary pilot tone 727,  
889 and null pilot tones, e.g. exemplary null pilot tone 721, across the three sectors. Since it  
890 is assumed that each of the sectors share the same frequency band, the corresponding  
891 tones between sectors will interfere with each other. Note that the position and order of  
892 the tones are shown for illustrative purposes only and may vary in different  
893 implementations.

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894  
895 In accordance with the invention, the downlink signal includes one or more cell  
896 null pilots, which are null tones that are shared by each of the sectors 701, 703, 705. In  
897 a cell null pilot 729, there is zero transmission power in each of the sectors 701, 703,  
898 705. In addition, the downlink signal includes one or more sector nulls 721, 723, 725  
899 where the transmission power is zero only in a subset of the sectors 701, 703, 705. In  
900 the same tone as the sector null pilot, it is desirable to have a pilot tone or a data tone  
901 whose transmission power is fixed and known to the WT 1300 in the other sectors. For  
902 example, sector S1 703 sector null pilot 723, has corresponding sector S0 701 pilot  
903 tone 731 and corresponding sector S2 705 pilot tone 737.

904  
905 In one embodiment shown in Figure 7, there are 4 pilots, 1 sector null pilot and 1  
906 cell null pilot in each sector 701, 703, 705. For example, sector S0 701 has four pilots  
907 731, 733, 735, 737, one sector null pilot 721, and one cell null pilot 729. These pilots  
908 are arranged such that each sector has two unique pilots, and then shares a pilot with  
909 each of the two other sectors. For example, sector S0 701 has unique pilots 735, 727;  
910 pilot 731 shares a tone frequency with pilot 737 of sector S2 705; pilot 733 shares a  
911 tone frequency with pilot 739 of sector S1 703. In addition, the sector null pilot for one  
912 sector coincides with pilot tones in the other sectors. For example, for the null tone 725  
913 in sector S2 705, a pilot 733, 739 is transmitted on the same tone in sectors S0 701 and  
914 S1 703, respectively. The locations of the pilot tones, the cell null tones and the sector  
915 null tones are known to both the BS 1200 and the WT 1300.

916

917       The pilots change their positions, or 'hop,' over time for various reasons such as  
918 frequency diversity. Figure 8 gives an example of the tone hopping of the pilots, cell  
919 null pilots, and sector null pilots. Graph 800 of Figure 8 plots frequency on the vertical  
920 axis 801 vs time on the horizontal axis 803. Each small vertical subdivision 805  
921 corresponds to a tone, which each small horizontal subdivision 807 corresponds to an  
922 OFDM symbol time. Each pilot tone 809 is represented by a small box with vertical  
923 shading. Each sector null pilot 811 is represented by a small box with horizontal line  
924 shading. Each cell null pilot 813 is represented by a small box with cross hatched  
925 shading.

926  
927       In an embodiment, the pilot tones essentially hop following a modular linear  
928 hopping pattern. In accordance with the invention, the sector null tones hop following  
929 the same modular linear pattern as the pilot hopping with the same slope value.  
930 Moreover, in one embodiment of the invention, the cell null pilot tones also hop  
931 following the same modular linear pattern as the pilot hopping with the same slope  
932 value.

933  
934       In an embodiment, the data tones essentially hop following a permuted modular  
935 linear hopping pattern. In another embodiment of the invention, the cell null pilots hop  
936 following the same permuted modular linear pattern as the data hopping. In that  
937 embodiment, when a cell null pilot tone collides with a pilot tone, either the transmission  
938 of the pilot tone in each of the sectors is suspended and the pilot tone is effectively  
939 erased, or the transmission of the pilot tone continues in at least some of the sectors  
940 and the cell null pilot tone is effectively rendered unusable.

941  
942       Suppose that the WT 1300 has a link established with sector S0 of the base  
943 station 1200, and that the channel gain from S0 to WT 1300 is given by  $\alpha$ . Similarly,  
944 suppose that the channel gain from S1 to WT 1300 is given by  $\beta$ , and from S2 to WT  
945 1300 is given by  $\gamma$ . Finally for completeness, suppose that the signal-dependent noise



in the link from S0 to WT 1300 includes self-noise that is proportional to the transmit power with a channel gain of  $\delta$ .

Suppose that the transmit power for the data tones on the three sectors is given by  $Q_0$ ,  $Q_1$ , and  $Q_2$ , respectively. Then the received SNR for the link from S0 to WT 1300 is given by

$$SNR_{s_0}(Q_0, Q_1, Q_2) = \frac{\alpha Q_0}{\delta Q_0 + \beta Q_1 + \gamma Q_2 + N}.$$

For the remainder of this discussion, it will be assumed that the interference due to the other sectors ( $\beta Q_1$  and  $\gamma Q_2$ ) is much more significant than the signal-dependent noise from the same sector  $\delta Q_0$ , so that for simplicity this term will be omitted in the subsequent discussion.

The WT 1300 should provide a set of parameters to the base station so that it has enough information to predict the received SNR for the downlink data transmission from S0 to WT 1300. To obtain that information, it may use the null pilot tones. Using a cell null pilot, in which the transmission in each of the sectors is 0, it is possible to measure the signal-independent noise. Comparing that with the received strength of the pilot from S0 gives the following SNR:

$$SNR_0(P) = \frac{\alpha P}{N}$$

Next, the sector null pilot tones can be, and in various embodiments are, used to measure the SNR in the situation when one of the neighboring sectors is not transmitting. In particular, for sector S0, consider the pilot tone that corresponds to a sector null pilot tone in S2. Then measuring the SNR based on this pilot in sector S0 will give the value

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$$SNR1^{\beta}(P) = \frac{\alpha P}{\beta P + N},$$

where the interfering sector is S1 (with path gain  $\beta$ ). Similarly, by measuring the SNR on the pilot tone that is a sector null tone in S1, the interfering sector is sector S2 (with path gain  $\gamma$ ), and the resulting SNR is given by

$$SNR1^{\gamma}(P) = \frac{\alpha P}{\gamma P + N}.$$

The slopes of the noise characteristic line in these two cases are  $\frac{\beta}{\alpha}$  and  $\frac{\gamma}{\alpha}$ , respectively.

Next, if the SNR is directly measured using pilot tones that do not correspond to sector null pilots in the other sectors, then this SNR measurement takes into account the interference from the other two sectors. This measurement is called SNR2, since it includes interference from two sectors.

$$SNR2(P) = \frac{\alpha P}{\beta P + \gamma P + N}$$

The slope of the noise characteristic line in this case is  $\frac{\beta + \gamma}{\alpha}$ .

By defining the following SRR as proper slope values of the noise characteristic lines, it is possible to relate  $SNR1^{\beta}(P)$ ,  $SNR1^{\gamma}(P)$ , and  $SNR2(P)$  to  $SNR0(P)$ :

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$$SRR2 = \frac{\beta + \gamma}{\alpha}$$

$$SRR1^\beta = \frac{\beta}{\alpha}$$

$$SRR1^\gamma = \frac{\gamma}{\alpha}$$

The SRRs themselves can be computed in terms of the SNRs as follows:

$$SRR2 = \frac{1}{SNR2(P)} - \frac{1}{SNR0(P)}$$

$$SRR1^\beta = \frac{1}{SNR1^\beta(P)} - \frac{1}{SNR0(P)}$$

$$SRR1^\gamma = \frac{1}{SNR1^\gamma(P)} - \frac{1}{SNR0(P)}$$

Note that  $SRR2$  can be found as the sum of  $SRR1^\beta$  and  $SRR1^\gamma$ .

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Then the SNRs can be written in terms of  $SNR0(P)$  and the SRRs:

$$SNR2(P) = \frac{SNR0(P)}{1 + SRR2 \cdot SNR0(P)}$$

$$SNR1^\gamma(P) = \frac{SNR0(P)}{1 + SRR1^\gamma \cdot SNR0(P)}$$

$$SNR1^\beta(P) = \frac{SNR0(P)}{1 + SRR1^\beta \cdot SNR0(P)}$$

If the WT 1300 reports a sufficient set of these statistics (e.g.,

$SNR0(P)$ ,  $SRR1^\beta$ ,  $SRR1^\gamma$ ,  $SRR2$ ) to the base station 1200, the base station 1200 can

predict the received SNR by the WT 1300 based on the transmit powers  $Q0$ ,  $Q1$ , and

$Q2$ . In general, the SNR as seen by the WT 1300 for a data transmission with power

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1016  $Q_0$ , with interference from sectors  $S_1$  and  $S_2$  with powers  $Q_1$  and  $Q_2$ , is given in terms  
1017 of the measurements made on the pilot tone with transmit power  $P$  as:

$$SNR_{s_0}(Q_0, Q_1, Q_2) = \frac{\alpha Q_0}{\beta Q_1 + \gamma Q_2 + N}$$

$$= \frac{SNR_0(P)}{\left( \frac{Q_1}{Q_0} SRR1^\beta + \frac{Q_2}{Q_0} SRR1^\gamma \right) \cdot SNR_0(P) + \frac{P}{Q_0}}$$

1020 In Figure 9, diagram 900 shows three situations for an exemplary WT in sector  
1021  $S_0$ . Cell 901 includes three sectors  $S_0$  903,  $S_1$  905, and  $S_2$  907. Fig 9 shows a WT  
1022 909 near the boundary with sector  $S_1$  905, where WT 909 receives significant downlink  
1023 interference from sector  $S_1$  905. Cell 921 including three sectors  $S_0$  923,  $S_1$  925, and  
1024  $S_2$  927 shows a WT 929 in the center of the sector  $S_0$  923, away from the sector  
1025 boundaries. Cell 941 including three sectors  $S_0$  943,  $S_1$  945, and  $S_2$  947 shows a WT  
1026 949 near the boundary with sector  $S_2$  941, where the WT 949 receives significant  
1027 downlink interference from sector  $S_2$  947.

1028  
1029 In an embodiment of the invention, for each of these three situations, the WT  
1030 sends a subset of the measured statistics to the BS 1200, in order to reduce the  
1031 amount of information conveyed on the reverse link, e.g., the uplink.

1032  
1033 In the situation shown in Figure 9 with respect to cell 901, suppose that the WT  
1034 909 in sector  $S_0$  903 receives significant interference from sector  $S_1$  905. Then a  
1035 coordinated scheduler 1225 for the base station can turn off the data transmissions in  
1036 sector  $S_1$  905 that interfere with the transmissions from sector  $S_0$  903 to the WT 909.  
1037 Meanwhile, the transmission in sector  $S_2$  907 is coordinated so that it has the same or  
1038 nearly the same transmit power  $Q$  as in sector  $S_0$ . Then the SNR seen by the WT 909  
1039 will be given by

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$$\begin{aligned} SNR_{s_0}(Q, 0, Q) &= \frac{\alpha Q}{\gamma Q + N} \\ &= \frac{SNR_0(P)}{SRR1' \cdot SNR_0(P) + \frac{P}{Q}} \end{aligned}$$

in which case it is sufficient to report  $SNR_0(P)$  and  $SRR1'$ .

Next, for the situation shown in Figure 9 with respect to cell 921, in which the WT 929 is not near a sector boundary, it is possible to transmit on most or all sectors without causing too much interference to the WT 929. In this case, suppose the base station scheduler 1225 makes the simplifying assumption that each of the three sectors should transmit data with the same power  $Q$ . Then the SNR seen by the WT 929 for a transmission from sector S0 923 is given by

$$\begin{aligned} SNR_{s_0}(Q, Q, Q) &= \frac{\alpha Q}{\beta Q + \gamma Q + N} \\ &= \frac{SNR_0(P)}{SRR2 \cdot SNR_0(P) + \frac{P}{Q}} \end{aligned}$$

In this case, it is sufficient to report  $SNR_0(P)$  and  $SRR2$ .

Next, for the situation shown in Figure 9 with respect to cell 941, the WT 949 is located near the sector boundary with sector S2 947. Since the WT 949 receives significant interference from sector S2 947, a coordinated scheduler 1225 for the base station 1200 can turn off the corresponding data transmissions in sector S2 947. Meanwhile, suppose the transmission for sector S1 945 is scheduled with the same transmit power  $Q$  as in sector S0 943. Then the SNR seen by the WT 949 will be given by

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$$SNR_{s_0}(Q, Q, 0) = \frac{\alpha Q}{\beta Q + N}$$

$$= \frac{SNR_0(P)}{SRR_1^P \cdot SNR_0(P) + \frac{P}{Q}}$$

in which case it is sufficient to report  $SNR_0(P)$  and  $SRR_1^P$ .

Hence, if the BS 1200 restricts the transmit powers such that they are equal to some value  $Q$  or are equal to 0, then in each of the three possible configurations, only a subset of information needs to be transmitted from the WT 1300 to the BS 1200. In particular, in one embodiment, the wireless terminal 1300 makes a decision as to which of the situations (e.g., as shown in Figure 9 cell 901, Figure 9 cell 921 and Figure 9 cell 941) the WT 1300 is currently in. This information can be transmitted by the WT 1300 to the BS 1200 as a two-bit Sector Boundary Indicator. The sector boundary indicator indicates wireless terminal position information relative to a sector boundary. The first bit could indicate whether the WT 1300 is on a boundary so that it is necessary to turn off the transmission in the neighboring sector. The second bit could indicate which of the two sectors causes more interference. Possible 2 bit sector boundary indicators are listed in the first column of Table 1 set forth below. The second column of Table 1 indicates noise contribution information. The third column lists the control action to be taken by the BS 1200 in response to receiving the corresponding sector boundary indicator. The fourth column lists the two channel quality indicator values reported given the corresponding reported sector boundary indicator listed in the same row.

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Sector Boundary Indicator	SNR	Other sectors	WT reports
00	$SNR_{s_0}(Q, Q, Q)$	Transmit on all sectors	SNR0(P), SRR2
10	$SNR_{s_0}(Q, 0, Q)$	Turn off sector S2	SNR0(P), SRR1 <sup>7</sup>
11	$SNR_{s_0}(Q, Q, 0)$	Turn off sector S1	SNR0(P), SRR1 <sup>8</sup>

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TABLE 1

In this way, since the WT 1300 identifies to the base station 1200 which configuration it prefers, the WT 1300 needs to only report SNR0(P) and one of the three SRRs.

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A multi-sector cell with an arbitrary number of sectors will now be discussed. In another embodiment of this invention, for the situation where there are an arbitrary number of sectors, the sectors are divided into three sector types, which we will label S0, S1 and S2. This classification into sector types is done in such a way that two adjacent sectors will not have the same type. It is assumed that for two non-adjacent sectors, the effect of interference is considered small enough as to not be significant, so that the main cause of interference is from adjacent sectors of different types. Hence it is possible to treat this situation in an analogous fashion to the case of the 3-sector cell, since the primary source of interference in each sector comes from its two neighboring sectors.

Figure 10 includes a diagram 1000 that shows the sector types for exemplary cells 1001, 1021, and 1041 with 3, 4 and 5 sectors, respectively. Cell 1001 includes a first sector S0 type sector 1003, a first sector S1 type sector 1005, and a first sector S2 type sector 1007. Cell 1021 includes a first sector S0 type sector 1023, a first sector S1

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1107 type sector 1025, a first sector S2 type sector 1027, and a second S1 type sector 1029.  
1108 Cell 1041 includes a first sector S0 type sector 1043, a first sector S1 type sector 1045,  
1109 a first sector S2 type sector 1047, a second S0 type sector 1049, and a second S1 type  
1110 sector 1051. Table 2 set forth below gives an example of a plan for different numbers  
1111 of sectors, where the order of the list of sector types corresponds to the order  
1112 proceeding (e.g., clockwise) around the sector.  
1113

Number of sectors	Sector types
1	S0
2	S0, S1
3	S0, S1, S2
4	S0, S1, S2, S1
5	S0, S1, S2, S0, S1
6	S0, S1, S2, S0, S1, S2
7	S0, S1, S2, S0, S1, S2, S1
8	S0, S1, S2, S0, S1, S2, S0, S1
9	S0, S1, S2, S0, S1, S2, S0, S1, S2

TABLE 2

1114  
1115  
1116  
1117 Using the above sector type scheme, the scheme involving cell null pilots and  
1118 sector null pilots for the case of three sectors can be used for an arbitrary number of  
1119 sectors.

1120  
1121 While described in the context of an OFDM system, the methods and apparatus  
1122 of the present invention are applicable to a wide range of communications systems  
1123 including many non-OFDM. In addition, some features are applicable to non-cellular  
1124 systems.  
1125



1126 In various embodiments nodes described herein are implemented using one or  
1127 more modules to perform the steps corresponding to one or more methods of the  
1128 present invention, for example, signal processing, message generation and/or  
1129 transmission steps. Thus, in some embodiments various features of the present  
1130 invention are implemented using modules. Such modules may be implemented using  
1131 software, hardware or a combination of software and hardware. Many of the above  
1132 described methods or method steps can be implemented using machine executable  
1133 instructions, such as software, included in a machine readable medium such as a  
1134 memory device, e.g., RAM, floppy disk, etc. to control a machine, e.g., general purpose  
1135 computer with or without additional hardware, to implement all or portions of the above  
1136 described methods, e.g., in one or more nodes. Accordingly, among other things, the  
1137 present invention is directed to a machine-readable medium including machine  
1138 executable instructions for causing a machine, e.g., processor and associated  
1139 hardware, to perform one or more of the steps of the above-described method(s).

1140  
1141 Numerous additional variations on the methods and apparatus of the present  
1142 invention described above will be apparent to those skilled in the art in view of the  
1143 above description of the invention. Such variations are to be considered within the  
1144 scope of the invention. The methods and apparatus of the present invention may be,  
1145 and in various embodiments are, used with CDMA, orthogonal frequency division  
1146 multiplexing (OFDM), and/or various other types of communications techniques which  
1147 may be used to provide wireless communications links between access nodes and  
1148 mobile nodes. In some embodiments the access nodes are implemented as base  
1149 stations which establish communications links with mobile nodes using OFDM and/or  
1150 CDMA. In various embodiments the mobile nodes are implemented as notebook  
1151 computers, personal data assistants (PDAs), or other portable devices including  
1152 receiver/transmitter circuits and logic and/or routines, for implementing the methods of  
1153 the present invention.

1154  
1155 Fig. 14 illustrates the steps of an exemplary method 1400 of transmitting pilot  
1156 tones in multiple sectors of a cell in a synchronized manner in accordance with the

1157 present invention. The method starts in start node 1402 and proceeds to step 1404  
1158 wherein a current symbol time counter is initialized, e.g., to 1. Symbols are transmitted  
1159 in the exemplary system on a per symbol basis with a symbol time being the time used  
1160 to transmit one symbol along with a cyclic prefix which is normally a copy of a portion of  
1161 the transmitted symbol that is added for redundancy to protect against multipath  
1162 interference and minor symbol transmission timing errors.

1163  
1164 Operation proceeds from step 1404 to step 1406 wherein the transmitter is  
1165 controlled to transmit pilot symbols to be transmitted in the current symbol time in each  
1166 sector in a synchronized manner using the same tones in each sector according to a  
1167 pre-selected pilot transmission sequence, e.g., pilot tone hopping sequence, using pre-  
1168 selected transmission power levels in each sector of the cell. While pilots are  
1169 transmitted in each sector of a cell in parallel, the power level transmitted on a tone  
1170 may be some pre-selected level or zero in the case of a null tone. While the  
1171 transmission times of pilot signals in each sector are generally synchronized, slight  
1172 timing offsets between sectors may occur. Thus, each sector may actually use a  
1173 different symbol transmission time period. However, the symbol times in each sector  
1174 are sufficiently synchronized that there is substantial overlap in the symbol times used  
1175 to transmit symbols in each sector. Normally the substantial overlap is such that the  
1176 symbol transmission start times are synchronized to be within at least a period of time  
1177 corresponding to the time used to transmit the cyclic prefix sometimes called the cyclic  
1178 prefix duration. Thus, there is normally substantial overlap in the symbol times of the  
1179 different sectors even if there is not perfect overlap in symbol times.

1180  
1181 Which tones are used for pilot tones during a particular symbol time is  
1182 determined from the tone information 1238 included pilot hopping sequence tone  
1183 information 1234 while the power to be used on a given tone in each sector of the cell is  
1184 determined from power level information 1236.

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1185  
1186 Once the pilot tones are transmitted for the current symbol time in step 1406  
1187 operation proceeds to step 1408 wherein a current symbol time count is incremented by

1. Then in step 1410 a check is made to see if the current symbol time has reached a maximum symbol time. If the current symbol time is equal to the maximum the current symbol time is reset to 1 so that the pilot hopping sequence can begin to repeat in step 1406. The periodic transmission of pilot tones continues to repeat according to the implemented pilot tone hopping sequence until base station transmission stop or some other event causes the pilot signal transmission process to be interrupted.

Referring now to Figs. 15-17 various exemplary pilot tone transmissions are shown along with pilot signal transmission power information.

In accordance with the present invention, pilot tones are transmitted using the same tones in multiple sectors of a cell at the same or substantially the same time. In various embodiments of the present invention the symbol transmission times are synchronized in the various sectors of the cell. Assuming perfect synchronization, there would be full overlap in terms of time between the pilot tones transmitted in the various sectors of a cell at any given time. Unfortunately, as noted above, precise synchronization may not be possible for a variety of reasons related to the complexity of synchronizing transmissions between different amplifiers and antennas operating at high frequencies. However, in synchronized sector implementations a substantial amount of overlap of symbol times exists between the sectors. Thus pilot transmissions can be achieved with substantial overlap making signal measurements which assume full overlap during at least a portion of each sectors symbol transmission time possible. As mentioned above, in the synchronized embodiment of the invention the difference between symbol transmission start times between the various sectors of a cell usually is less than the duration of the cyclic prefix which is normally included with transmitted symbols.

For purposes of discussion, it will be assumed that there is full synchronization with signals, e.g., symbols, being transmitted at the same time in a synchronized manner in each sector of a multi-sector cell. However, the above discussion makes it clear that such precise synchronization normally does not occur and is not required to

1219 practice the invention. Thus, the transmission in each sector corresponds to a different  
1220 symbol time which may be slightly offset from the symbol time of the adjacent sector.  
1221 In accordance with the present invention, while pilot tones are transmitted in each  
1222 sector of a cell on the same set of tones in a synchronized manner, the power of the  
1223 pilot tones in different sectors of a cell are controlled to permit different signal  
1224 measurements which facilitate, in a particular sector, determining the noise contribution  
1225 from other, e.g., adjacent sector(s) as well as background noise.

1226  
1227 To facilitate multiple different signal measurements, multiple pilot tones may be  
1228 used during a single symbol transmission time. Alternatively, one pilot signal may be  
1229 used per symbol time with the pilot signal being assigned different power levels during  
1230 different, e.g., successive, symbol times. In such a case, the pilot signal measurements  
1231 made during different symbol times may be used to produce the two different channel  
1232 quality indicator values which are returned to the base station in accordance with the  
1233 invention.

1234  
1235 Fig. 15 is a chart 1500 showing a two-sector pilot tone transmission sequence  
1236 implemented in one exemplary embodiment of the present invention. As will be  
1237 discussed below, the sequence shown in Fig. 15 can be extend to systems with N  
1238 sectors, where N is an arbitrary number greater than 1. The sequence shown in Fig. 15  
1239 is implemented for a cell which includes two sectors, sector A and sector B. The  
1240 symbol times in each sector may be slightly offset but substantially overlap and  
1241 therefore will be described as the same symbol time although actually being two slightly  
1242 different symbol times in many cases. The first column 1502 titled time refers to the  
1243 symbol time in which a tone is transmitted assuming perfect synchronization between  
1244 sectors. In one embodiment, where the same tone is used in each symbol time for pilot  
1245 signal purposes, each symbol time 1 through 4, corresponds to a different current  
1246 symbol time. The second column 1504 titled TONE lists the tone, e.g., frequency, on  
1247 which the pilot signals are transmitted. Each row corresponds to one tone. Different  
1248 rows may correspond to the same or different tones depending on the particular  
1249 implementation. For example, in cases where the first through fourth symbol times are

the same current symbol time, then the first through fourth tones listed in column 1504 will be different since each pilot signal requires one tone. However, in cases where the first through 4<sup>th</sup> symbol times in column 1502 correspond to different current symbol times, the tones listed in column 1504 may be the same or different.

As discussed above each row 1512, 1514, 1516 and 1518 corresponds to the transmission of a tone in each of the cells sectors A and B, e.g., a tone used to transmit a pilot signal. The transmission power levels in each of the sectors may be different or the same. In each case, the pilot tone transmitted at any point in time is transmitted with a pre-selected transmission power. Thus, the transmission power and tone on which a pilot signal is transmitted will be known to both the base station 1200 and wireless terminals 1300 since this information is stored in both devices and both devices know the current symbol time from timing information available in the cell. In Fig. 15, the third column 1506 lists the pilot signal transmission power level for the pilot signal transmitted in sector A using the tone to which the particular row corresponds. Similarly the fourth column 1508 lists the pilot signal transmission power level for the pilot signal transmitted in sector B using the tone to which the particular row corresponds. Column 1510 is included for purposes of explaining a 3 sector embodiment later but is not used in the two sector implementation being described in regard to Fig. 15.

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Each rectangle in column 1506 and 1508 represents a step of transmitting a pilot signal in the indicated sector at the general symbol time indicated in column 1502 using the tone indicated in column 1504. In practice, the tones are transmitted at slightly different symbol times in each of sectors A and B, e.g., first and second symbol times which correspond substantially to the symbol time listed in column 1502. A 1 is used to indicate a non-zero pilot having a first pre-selected transmission power while a zero is used to indicate transmission of a null tone, e.g., a pilot signal with transmitted with zero power.

1280 Row 1512 shows that at symbol time 1, using tone 1, a 1 pilot signal is  
1281 transmitted in sector A while a NULL pilot signal is transmitted in sector B. This makes  
1282 it possible to measure the contribution of inter-sector interference in sector B caused by  
1283 sector A transmission on the same tone. It also allows sector A to make accurate  
1284 measurements of the attenuation in sector A without the presence of interference due  
1285 to sector B transmission. Row 1514 corresponds to symbol time 2 wherein tone 2 is  
1286 used to transmit a NULL tone in sector A and a 1 pilot signal in sector B. This allows  
1287 sector A to determine the amount of signal interference due to sector B transmission on  
1288 the same tone. Row 1516 corresponds to symbol time 3 wherein tone 3 is used to  
1289 transmit a NULL pilot signal in both sectors A and B making general background noise  
1290 measurements possible on tone 3. Row 1518 corresponds to symbol time 4 wherein  
1291 tone 4 is used in both sectors A and B to transmit 1 pilot signals. In such a case each  
1292 sector can measure the effect of having a signal transmitted with the same non-zero  
1293 power level in each of sectors A and B at the same time. Normally pilot signals are  
1294 transmitted in accordance with both the first and second rows 1512, 1514 of Fig. 15 and  
1295 at least one of rows 1516 and 1518 in order to provide a wireless terminal to make  
1296 sufficient signal measurements which required as input to the two different functions  
1297 used to generate the first and second channel quality indicator values that are feedback  
1298 to the base station 1200 in accordance with one feature of the invention.

1299  
1300 Fig. 16 is a chart 1600 illustrating an exemplary pilot tone transmission  
1301 sequence for a three sector system. As in the Fig. 15 example, the first column 1602  
1302 corresponds to symbol transmission time, the second column 1604 corresponds to tone  
1303 while columns 1606, 1608 and 1610 indicate pilot signal transmissions in each of three  
1304 sectors A, B and C of a cell, respectively. Thus, as in the Fig. 15 example, each  
1305 rectangle of column 1606, 1608 and 1610 which corresponds to one of the first through  
1306 fifth rows, 1612, 1614, 1616, 1618, 1620 represents the step of transmitting a pilot  
1307 signal on the indicated tone in the indicated sector. While the tones used in each row  
1308 are the same in each sector, as discussed above, when each of the symbol times  
1309 corresponds to the same current symbol time, the each of the first through fifth tones

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will be different. However, when each of the first through fifth symbol times are different the first through fifth tones may be the same or different.

Note that in the Fig. 16 implementation, at least one pilot signal is transmitted for each sector with a null pilot being transmitted on the same tone in an adjoining sector. Also note the use in row 1620 of what has been described as cell null which facilitates background noise measurements.

Fig. 17 is a chart 1700 showing a three sector implementation similar to Fig. 16 with the pilots transmitted in each sector being described in a more general manner in terms of power levels. The transmission of 15 pilots P1 through P15 are shown in the Fig. 17 embodiment with each pilot being transmitted at a different symbol time in the case where each row corresponds to a different transmission symbol period. In the case where each of the listed signals are to be transmitted in the same symbol time, three different symbol times are shown, with the transmission time of each sector being slightly different but corresponding to substantially the same symbol time as used in the other sectors.

As in the Fig. 15 and 16 examples the pilots of each row 1712, 1714, 1716, 1718, 1720 are transmitted using the same tone but different rows may correspond to different tones. While being shown as being transmitted at 5 different symbol times as listed in the first column 1702, when variations in sector transmission times is taken into consideration each rectangle listed on the heading Sector may actually correspond to a different symbol time with the symbol times of each row substantially overlapping and being identical in the case of precise synchronization. The power level of each of the first through 15<sup>th</sup> pilots P1 through P15 are represented in parenthesis, e.g., the transmission power for P1 is p1. While in some cases such as in the Fig. 16 example two different power levels are supported, multiple known power levels may be supported. The last row 1720 of Fig. 17 represents the transmission of a NULL pilot signal using tone 5 in each of sectors A, B and C according the power level of these pilot signals is 0 in each case.

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1341  
1342 Fig. 18 illustrates a chart 1750 showing the transmission of signals on 10  
1343 different tones during a single symbol transmission time period. In the Fig. 17  
1344 implementation the 0 is used to represent a NULL pilot signal, while a 1 is used to  
1345 represent a pilot at a single known non-zero transmission power level which is normally  
1346 higher than the power level at which data is transmitted. D is used in the chart 1750 to  
1347 illustrate the transmission of data in one of the sectors A, B and C. The data signal D is  
1348 usually transmitted on the tone at a power level lower than the pilot signal level 1 and  
1349 therefore may not cause significant interference with the pilot in the neighboring sector.  
1350 Data is normally transmitted in each of the sectors on additional tones not shown in Fig.  
1351 17 during the illustrated symbol time. In the OFDM embodiment of the present  
1352 invention, in a given sector such additional data tones do not interfere with the pilot  
1353 tones since they are orthogonal to the tones used to transmit pilot signals. Fig. 19  
1354 illustrates a method 1800 of operating a wireless terminal to process pilots signals  
1355 received from a base station 1200, which were transmitted in accordance with the  
1356 present invention. The received pilot signals may be pilot signals that were transmitted  
1357 with known different transmission power levels allowing the receiving device to make  
1358 various signal measurements and computations useful for determining various noise  
1359 contributions, e.g., background noise as well as inter-sector interference.

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1360  
1361 The method 1800 starts in start node 1802 and proceeds along two processing  
1362 paths beginning with steps 1804 and 1808, respectively. The two processing paths  
1363 may be implemented in parallel, e.g., in the case where multiple pilot signals with  
1364 different transmission power levels are transmitted during a single symbol time, or in  
1365 series, e.g., in the case where pilots are transmitted sequentially using the same tone  
1366 but different power levels during different symbol transmission times.

1367  
1368 In step 1804, the wireless terminal 1300 measures at least one of an amplitude  
1369 and a phase of a first pilot signal that was transmitted with transmission power P1 to  
1370 produce a first measured signal value. The first measured signal value is then used in  
1371 step 1806. In step 1806, a first channel quality indicator value is generated from the



1372 first measured signal value according to a first function, f1, which uses at least said first  
1373 measured signal value as an input. The first channel quality indicator value generated  
1374 by function f1 may be, for example, an SNR value or a signal power value,  
1375 corresponding to said first received pilot signal. Function f1 may use other signal  
1376 measurements and/or other information as inputs in addition to the first measured  
1377 signal value when generating the first channel quality indicator value. Operation  
1378 proceeds from step 1806 to step 1812.

1379  
1380 In step 1808, which may be performed in parallel with step 1804 in some  
1381 embodiments, the wireless terminal 1300 measures at least one of an amplitude and a  
1382 phase of a second pilot signal which was transmitted with transmission power P2,  
1383 where P2 is different from P1. The measurement produces a second measured signal  
1384 value which is then used in step 1810. In step 1810 a second channel quality indicator  
1385 value is generated from the second measured signal value according to a second  
1386 function, f2, which uses the second measured signal value as an input. The second  
1387 function is different from said first function and uses at least the second measured  
1388 signal value as an input but may also use other signal measurements as inputs as well.  
1389 In some embodiments, the second channel quality indicator value generated by the  
1390 second function is an SNR value corresponding to the second pilot signal while in other  
1391 embodiments it is a signal power value, e.g., an indicator of received signal power,  
1392 corresponding to the second pilot signal. Operation proceeds from step 1810 to step  
1393 1812.

1394  
1395 In step 1812, the wireless terminal 1300 determines the location of the wireless  
1396 terminal relative to one or more sector boundaries from measured signal values and/or  
1397 other boundary location indicator value information discussed above. Using the relative  
1398 boundary location and/or other information generated in step 1812, in step 1814 the  
1399 wireless terminal 1300 generates a boundary location indicator value 1814, e.g., having  
1400 a value corresponding to one of the values shown in column 1 of Table 2. With the first  
1401 and second channel quality values from steps 1806 and 1810, and the boundary

1402 location indicator value from step 1814, operation proceeds to transmit step 1816  
1403 wherein the generated information is transmitted back to the base station 1200.  
1404

1405 Step 1816 involves the transmission of the first and second channel quality  
1406 indicator values and the boundary location indicator value, e.g., as part of one or more  
1407 messages. Two alternative processing paths are shown with a single processing path  
1408 being used in any particular implementation. The first processing path beginning with  
1409 sub-step 1820 and ending with 1826 represents the case where various information is  
1410 included in a single message. The second processing path beginning with step 1830  
1411 and ending with step 1840 corresponds to the case where different messages are used  
1412 to transmit each of the various values. Messages in this context are to be interpreted  
1413 broadly and include signals which convey the particular values to be communicated.  
1414

1415 In step 1820, the first channel quality indicator value is incorporated into a first  
1416 message. Then, in step 1822 the second channel quality indicator value is  
1417 incorporated into the first message. Next, in step 1824 the boundary location indicator  
1418 value is incorporated into the first message. The first message is then communicated  
1419 to the base station 1200 in step 1826, e.g., by transmitting the first message over a  
1420 wireless communication link. This is done in various embodiments using one or more  
1421 dedicated time slots of a control channel used to report channel quality and/or other  
1422 feedback information from wireless terminals to the base station 1200. As a result of  
1423 the dedication of the time slot to the wireless terminal using it to report channel quality  
1424 and other information, other wireless terminals or devices in the sector will not use the  
1425 time slot. Thus, through the use of dedicated time slots transmission conflicts are  
1426 avoided. Furthermore, given that the channel is dedicated to communicating particular  
1427 control information, the values may be generated and transmitted in the time slots  
1428 without having to send headers or other information indicating what the meaning of the  
1429 transmitted values are. That is, the base station 1200 knows that values transmitted in  
1430 the utilized control channel are to have a certain pre-selected format and represent,  
1431 e.g., first and second channel quality indicator values followed by a two bit boundary  
1432 location indicator value. Thus, the amount of overhead, e.g., header overhead, used to

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transmit such messages and/or values can be minimized. With the transmission of the generated values having been completed in step 1826, operation returns to steps 1804 and 1808 wherein signal measurements are made on new pilot signals with the feedback process continuing to repeat over time.

In step 1830, which corresponds to the alternate value transmission path shown in step 1816, the first channel quality indicator value is incorporated into a first message, e.g., a signal, which is then transmitted to the base station in step 1832. Then, in step 1834 the second channel quality indicator value is incorporated into a second message, e.g., signal, which is transmitted in step 1836. The boundary location indicator value is incorporated in step 1838 into a third message, which is then transmitted to the base station 1200 in step 1840. As in the case of the combined message transmitted in step 8126, the individual messages transmitted in steps 1832, 1836 and 1840 may be transmitted using dedicated segments of a control channel dedicated to the communication of feedback information. Operation proceeds from step 1840 to steps 1804 and 1808 with the processing of generating the channel feedback information and reporting the information to the base station 1200 repeating over time.

Figure 20 shows a flowchart 1900 illustrating a method of operating base station (BS) 1200 in accordance with the present invention, e.g., to transmit pilot tones and to receive and process feedback information to determine the power level at which to transmit data signals. The method starts with step 1902 where the base station 1200 is powered on and operational. In step 1904, base station's transmitter 1204, coupled to a multi-sector antenna 1205, ~~transmits pilot signals into each sector, e.g. S0 1106, S1 1108, S2 1110 of a multi-sector cell, e.g., 1104 at the same time in a synchronized manner using predetermined power levels and tones such that the transmission of the pilot tones into each of the sectors 1106, 1108, 1110 of the cell 1104 use the same set of tones and are transmitted at substantially the same time in each of the sectors 1106, 1108, 1110. The transmission of pilot tones in step 1904 is performed under the direction of the pilot signal generation and transmission control routine 1230 using pilot~~

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1464 tone power level info 1236 and tone info 1238. Operation proceeds to step 1906 where  
1465 BS 1200 receives messages from at least one wireless terminal (WT) 1300 including,  
1466 e.g., a set of channel quality indicator values, e.g., first and second channel quality  
1467 indicator values, and sector boundary position information. The messages are received  
1468 under the direction of the received signal processing routine 1260 included in base  
1469 station 1200. In step 1908, the base station, under the direction of channel quality  
1470 indicator value extraction module 1262 extracts at least two different channel quality  
1471 indicator values 1250, e.g., from a single message or from multiple messages received  
1472 from a wireless terminal 1300. In some embodiments each channel quality indicator  
1473 value is in a separate message. In other embodiments multiple channel quality indicator  
1474 values are include in a single message from a WT 1300. Next, in step 1910, the base  
1475 station 1200, under control of position information extraction module 1264, extracts  
1476 location information from received messages, e.g., boundary position indicator value,  
1477 indicating the position of a wireless terminal 1300 relative to a boundary in a multi-  
1478 sector cell. This location information may have been transmitted by WT 1300 in a  
1479 separate message or may have been included in a message including channel quality  
1480 indicator values. This location information may identify whether the WT 1300 is near a  
1481 sector boundary, and identify which sector boundary, e.g., identify the adjacent sector  
1482 from which a higher level of transmission power dependent interference is being  
1483 received. Sector boundary information extracted from received messages is stored in  
1484 sector boundary position information 1252 in BS 1200.

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1486 Proceeding to step 1912, the base station 1200, under the direction of  
1487 transmission power calculation routine 1226 calculates from at least first and second  
1488 channel quality indicator values 1250 an amount of transmission power required to  
1489 achieve a desired signal to noise ratio at said wireless terminal 1300 from which said  
1490 first and second channel quality indicator values 1250 were received. In step 1914, the  
1491 base station scheduler module 1225 operates to make scheduling decisions for the  
1492 wireless terminals 1300. In sub-step 1916, the base station scheduler 1225 makes  
1493 decisions for the WT 1300 based on determined SNR, e.g., BS 1200 schedules  
1494 segments to the WT 1300 on channels with transmission power levels that will result in

1495 a received SNR of the WT 1300 exceeding the minimum acceptable level for the data  
1496 rate and coding scheme used. In sub-step 1918, the BS 1200 scheduler 1225 makes  
1497 decisions for the WT 1300 based on sector boundary position information 1252, e.g.,  
1498 for a WT 1300 identified as being near a sector boundary; base station 1200 assigns  
1499 channel segments to the WT 1300, with corresponding channel segments in the  
1500 adjacent sector having no transmission power. Proceeding to step 1920, BS 1200  
1501 transmitter 1205 transmits signal, which may include, e.g., user data 1244 that has  
1502 been encoded by encoder 1214, under direction of signaling routine 1228 at a  
1503 scheduled time to said WT 1300 using transmission power determined from said at  
1504 least two channel quality indicator values 1250 that were received.

1505  
1506 Operation proceeds from step 1920 back to step 1904 and the method is  
1507 repeated. Base station 1200 will be repeating the transmitting pilot signals in a  
1508 synchronized manner into each sector of the multi-sector cell in step 1904, on a regular  
1509 basis. However, different wireless terminals 1300, may send messages including set of  
1510 channel quality indicator values 1250 and sector boundary position information 1252 at  
1511 different times and/or different rates depending on factors such as the state of operation  
1512 the wireless terminal is in, e.g., on, hold, sleep.

1513  
1514 The invention is directed to, among other things, machine readable medium such  
1515 ~~as memory, compact disks, etc. including machine executable instructions, e.g.,~~  
1516 software modules or commands, for controlling a processor or other device to perform  
1517 processing in accordance with one or more of the various method steps of the  
1518 invention. Various features of the methods and apparatus of the invention can be used  
1519 in a wide range of communications systems including, but not being limited to, OFDM,  
1520 CDMA and other types of communications systems.

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